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Environmental Rehabilitation: Efficiency and Effectiveness in Soil Remediation

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Environmental rehabilitation: efficiency and effectiveness in soil remediation

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ABSTRACT

Soil cleaning-up operations have become a priority in most western countries. In the Netherlands, in particular, a systematic effort to restore the environmental quality of polluted sites has started in the early eighties. The cornerstone of the Dutch legislation is that of restoring soil multifunctionality, which allows the cleaned site to be used for any purpose, without functional constraints. In more than ten years of application, this approach has shown some weak points. First, the costs of cleaning-up may be extremely high. Many companies tend to delay as much as possible the operations, either to delay expenditures or to wait for the development of more effective cleaning-up technologies. Second, many cleaning-up techniques achieve very good results in terms of soil quality, but result into a transfer of pollution to other environmental media (for instance, air and water) and require an intensive use of scarce resources (for instance, energy, groundwater and space). Third, in many instances the site has a unique destination, an industrial site for instance, and cleaning-up beyond the level strictly necessary is very cost-inefficient.

These considerations have lead to the development of a new approaches for soil cleaning-up and to the development of methodologies and instruments for addressing effectiveness and efficiency in soil remediation. The paper shows a Decision Support System which assists the planning of cleaning-up operations on the basis of: (1) their effectiveness in reducing the risks for the specific needs of the site; (2) their capacity of minimising the negative influences on the environment and on the depletion of scarce resources; (3) the possibility of minimising the costs of operation and of timing the cleaning-up investments. The paper focuses on the environmental quality part, showing how the negative influences of cleaning-up operations can be taken into account in the evaluation of cleaning-up alternatives. Application examples are also provided.

INTRODUCTION

Soil pollution has become a priority in many industrialised countries after the inventory of various locations in which contamination was posing a risk to people and the environment. Table 1 shows the results of a recent survey of the number of contaminated sites within the territory of the European Union. This table highlights two main issues. The first is the sheer number of contaminated sites, which exceeds 500.000. The second is the very high variability in the national figures. Although EU countries share different levels of industrialisation and environmental degradation, this variability is mainly due to the lack of a coherent approach to the identification of polluted sites and to the different schemes used for classifying the urgency of cleaning-up. As an example, the high Dutch figure includes polluted sites and seriously polluted sites (classified according to the Dutch law). The number of seriously polluted sites, however, is around 50,000, which means about one fourth of the total number of listed sites.

The estimated costs for the cleaning-up operations range between 300 and 800 billion ECU. On this basis, soil pollution raises several important issues. The first is how to tackle soil remediation programmes to improve environmental quality in an effective way. The second is how to achieve this result in an economically sound way, given the enormous expenditures which are likely to be involved. The third is how to harmonise the operations across Europe and how to design a coherent and sound approach to the estimation of pollution extent and seriousness.

Table 1. An estimate of the number of polluted sites in Europe (Okx et al. 1996).

Austria	24,155
Belgium	9,000
Denmark	10,000
France	667
Germany	143,252
Greece	
Ireland	
Italy	9,805
Luxembourg	
The Netherlands	200,000
Portugal	
Spain	4,532
Sweden	1,700
United Kingdom	100,000
Total EU	502.444

The effects of soil contamination are manifold:

- Soil pollution is a source of risk for humans and ecosystems, which are (potentially) affected by direct exposure to the contaminated surface or by indirect exposure, for instance through contaminated groundwater.
- Soil contamination is a source of risk for ground works (like pipelines or utility networks) due to the chemical properties of the contaminant and the risk of ignition and explosion, for instance for fuel contamination.
- For publicly owned sites, a polluted area is a severe planning constraint, since

the site use may be impossible or limited to a specific soil functionality (e.g. a industrial storage facility).

- For privately owned sites, a polluted area is a heavy economic burden in terms of asset values, of remediation expenditures (a net cost for the company) and of soil usage.
- The presence of polluted areas may hinder and delay some specific developments which imply land use and ground works (like the provision or maintenance of infrastructures).
- Remediation expenditures do not offer any increase in productivity, merely the possibility of removing a source of risk and a planning constraint.

Large scale soil remediation in the Netherlands started in the early eighties, with the introduction of the Soil Clean-up Guideline (VROM, 1983; updated every two years). The guideline specifies how to evaluate the soil state and the remediation urgency. It also states that the ultimate objective of the operations is to eliminate the risks to man and the environment and to prevent the dispersion of pollution, that is to restore multifunctionality in the shortest possible time. Soil multifunctionality requires that the soil on the site after sanitation should pose no harm to humans, animals or plants, regardless of the use of the site, the type of soil, the type of pollutants and the local situation. This is a very demanding objective, totally driven by environmental quality considerations. There is, however, a growing awareness that other criteria should be included when assessing remediation strategies. One of the reasons is that the costs involved in multifunctional operations are no longer political defendable. There is also a growing recognition that clean-up operations do not necessarily lead to a positive environmental balance. Soil remediation requires the use of resources (like energy and clean water) and may lead to a net transfer of contamination to other compartments (for instance, due to air emissions). Therefore, the single perspective implied by the multifunctionality may result into an approach which disregards many relevant concerns for soil remediation.

ISSUES IN SOIL REMEDIATION

Multifunctionality has proven very difficult to achieve in practice. In the Dutch experience, about 50% of the cleaned-up soil does not meet the multifunctionality target and has to be used under additional constraints (Soczó et al., 1993). Achieving multifunctionality may be hampered by the cost of the operations and by technical and feasibility constraints. Technology for soil remediation is developing very quickly with a shifts from radical, hard solutions (such as excavate-pump-and-treat) to biological techniques which, for instance, exploit natural attenuation phenomena (cf. Arendt et al. 1983). However, the costs issues is still a mayor constraint to soil remediation. High costs have become both politically indefensible, and economically unfeasible.

The Dutch experience shows that the compliance pool to the soil directive has been much inferior than expected. Facing sheer expenditures, companies have often applied a wait-and-see attitude, delaying the operations as much as possible often exploiting the ambiguities of the guideline and the possibility of some discretionary interpretation of the law. The main issue raised by the private sector is that the multifunctionality objective systematically disregards efficiency and effectiveness considerations. Most companies do know what the future use of contaminated sites will be, and thus question the general principle that all sites should be cleaned-up to the same extent. An industrial area may need less strict measures than a residential one. In addition, the application of soft, but long, remediation techniques may significantly cut costs, although may delay the soil usage and leave many sites polluted for a considerable time.

Although the cost-related matters are clear, the multifunctionality objective may also raise some environmental concerns. Robberse and Denneman (1993) consider multifunctionality as the soil-related interpretation of sustainability. An implicit, and almost universal, assumption is that by cleaning-up a polluted site (or rehabilitating any degraded area) there is a net environmental benefit. A growing evidence has been provided that suggests that this assumption should be challenged and that the overall environmental balance of remediation may not be always positive (Laar et al., 1997). By considering the full life cycle of the remediation process, it can be recognised that the process requires the use of natural resources like energy and clean water, and may result into a transfer of pollution to other environments, for instance by creating air pollution, water pollution and waste. The soil remediation thus raises two types of environmental concerns:

1. A local, site specific concern, related to the need of reducing contamination below some safe level. This is clearly the positive site of the coin, in the sense that soil remediation provides a net local benefit.
2. A regional or even global concern, related to the need of minimising the use of scarce resources during the operations and the spread and transfer of pollution to other environments. These factors are the negative side of the remediation and cannot be disregarded in computing the full environmental balance of remediation.

Figure 1 synthesises these concepts by providing a bird's eye of soil remediation. This figure shows that multiple perspectives in soil remediation and the main concerns which have to be addressed to achieve environmental effectiveness and economic efficiency of the operations'.

[1] During 1997 the Dutch Ministries of Economic Affairs and of Environment have announced that the multifunctionality framework will be abandoned in the near future to introduce measures which allow to target efficient and effective soil remediation. The new directive is likely to be in force during 1988.

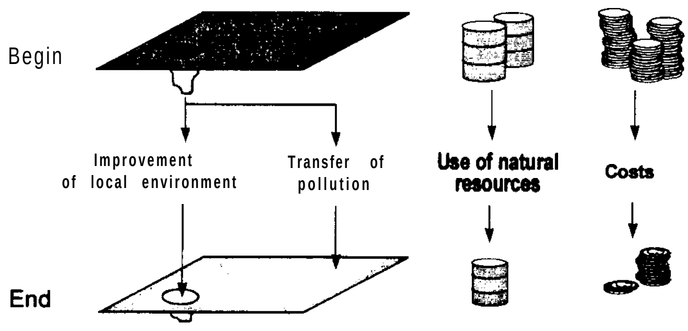

Figure 1. A bird's eye view of soil remediation.

EFFECTIVENES- EFFICIENCY: A FRAMEWORK FOR EVALUATION

The decision on how to clean-up a site can be divided into several successive phases. The first decisions is that of weather a polluted site needs to be cleaned up. If remediation is not necessary, then the investigations can be stopped. Otherwise, the investigations should be focussed on the screening of the suitable remedial strategies. The criteria which will influence this last decision are:

- the total impact of remediation strategy on the total risk for humans, ecosystem and infrastructures;
- the total impact of the remediation strategy on scarce commodities, such as soil, ground water, drinking water, space and energy, and on the quality of the environment as a whole;
- the total impact of the remediation strategy and method on the financial assets of the problem owner (Nijhof et al., 1996).

The REX-framework (Nijhof *et al.,* 1996; Drunen *et al.,* 1997), takes ***risks***, ***environmental merits*** and ***costs*** into account simultaneously, and hence aims at optimising a three-fold perspective (

Figure 1). The risk reduction perspective aims at minimising effects of contamination and remediation on targets (humans, ecosystems, objects) at the site. This perspective is the closest to the original evaluation framework aiming at multifunctionality. The environmental merit perspective, stemming from an Life Cycle Inventory approach, aims at minimising the use of scarce commodities and the contamination of other compartments due to remedial activities. The costs perspective aims at minimising the total costs in terms of net present value.

The methodology aims at producing, for each cleaning-up option, a set of three indices: the amount of risk reduction achieved by the remediation; the environmental balance of the operations and the costs involved. A synthetic overview of the functioning and results of the method is presented in Figure 3.

Risk reduction is based on the computation of the overall exposure of people, ecosystems and other targets (e.g. workers on the site during remediation) and at the comparison of the exposure levels with acceptability standards. Risks are computed during all phases of the operations, leading to a time-dependent profile of the risk attenuation process. By comparing this to the risk profile of the status quo, the amount of risk reduction can be computed. This index is expressed in Risk Units (ru). Environmental merit (which will be explained in detail in the following sections) is based on the computation of an additive index for multiple environmental consequences of roil remediation. The non-local positive and negative outcomes of soil clean-up are weighted and summed up leading to an indication of the environmental performance of the operations. These are compared again to the status quo (which corresponds to the O-level of environmental merit). The index is here measured in Environmental merit Units (eu) (see below). Finally, the costs include all costs involved in the operations, including asset costs. Costs are computed yearly for the full length of the operations. The Net Present Value is then used as an estimate of the total costs. Each cost item is the sum of the expected cost in a given period plus a safety quantity to guarantee that the real costs will have only a limited probability of exceeding the computed costs. The rest of the paper will focus on the environmental merit perspective and on the construction of an environmental merit index for soil remediation.

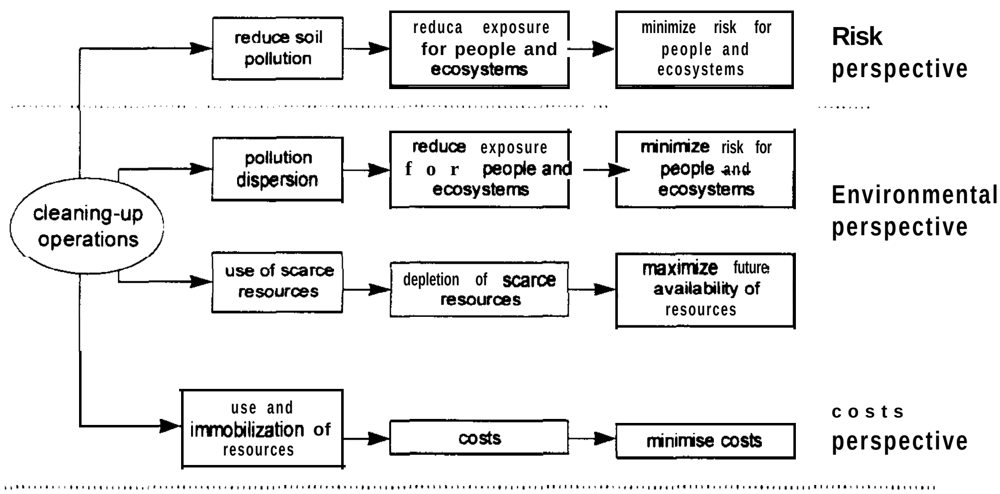

Figure 2. Three perspectives for soil remediation

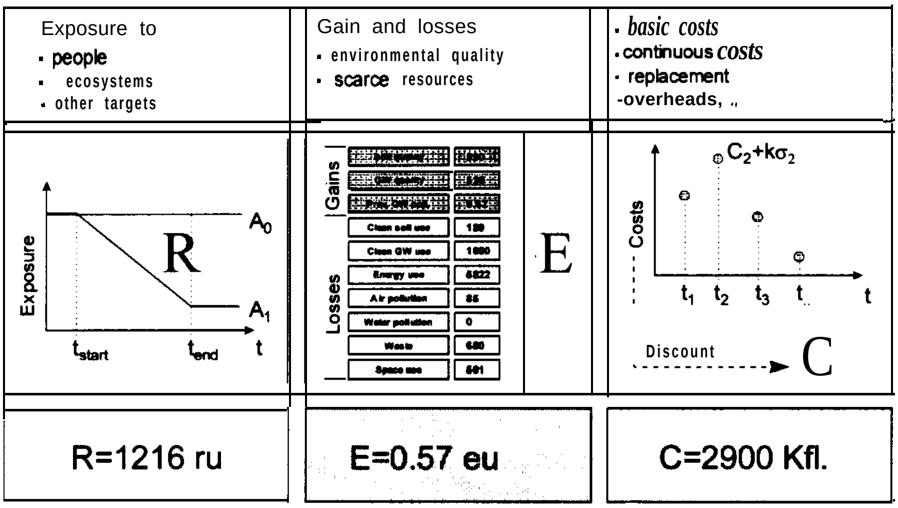

Figure 3. An overview of the REC models and of the results of the three REC indices.

THE ENVIRONMENTAL MERIT PERSPECTIVE

The rationale behind the Environmental perspective is that clean-up operations determine environmental costs and benefits beyond those encompassed by the risk assessment. A clean-up operation may result into the use of scarce resources, such as energy, transfer the pollution to other compartments, such as emissions to surface water during operations, and to secondary effects, like the emission of green house gasses due to combustion of fossil fuels. These consequences cannot be grasped by neither the risk analysis, nor by the traditional financial assessment carried out before remediation. This cost assessment usually does not include valuation of environmental goods, and thus internalisation of the values of environmental resources.

The evaluation of clean-up operations in terms of environmental merit are based on an Environmental Merit Index (EMI). This index is constructed by rating the performances of clean-up options against a list of measurable aspects and by aggregating these performances with a weighting scheme. The main steps for constructing the EM1 are based on multicriteria value functions (cf. Beinat, 1997) and can be described as follows:

Step 1. Select a list of measurable variables which determine the environmental quality of a remedial option.

Step 2. Quantify the performances of each remedial alternative along each of these aspects.

Step 3. Establish a value functions for each aspect. This serves to transform performance scores into a comparable scale.

Step 4. Establish the weights for each aspect. Weights represent the relative contribution of each aspect to the EMI. Intuitively, a weight states how important an aspect is compared to another.

Step 5. Calculate the weighted sum of the normalised scores resulting in the EM1 index for an alternative.

The aspects which are considered in environmental merit are a cross section of the typical Life-Cycle-Inventory aspects and of the specific aspects relevant to soil remediation. The reasons for going beyond the LCI indications can be summarised in three points:

1. LCI applied to soil remediation does not cover all aspects which are considered relevant by soil remediation practitioners. The amount of space used-up by the remedial actions, for instance, is considered as a relevant decision factor in soil management, especially where space is a scarce resource.
2. The LCI inventory provides a list of impacts with a strong emphasis on global effects (such as acidification, eutrophication, global warming, etc.). In soil remediation, not only global effects, but also regional and local considerations are important. This calls for a more balanced selection of evaluation criteria.
3. The LCI aspects are not suitable for a simple integration. Suitable aspects need to respect some fundamental properties, such as independence and prevention of double counting. If these properties are respected, then linear weighted schemes can be used for integration. Otherwise, non-linear forms are necessary and empirical evidence suggests that these forms become easily too complex to be of practical relevance (Beinat, 1997).

The analysis of the practice of LCI and soil remediation and interviews with expert panels led to the selection for the list of aspects shown in Table 2. These aspects include the positive outcomes of remediation in global environmental terms (an increase of the quality of the soil stock, an increase of the quality of the groundwater stock and a prevention of future contamination of the groundwater). However, this usually comes at a cost, represented by a depletion of resources (a net consumption of soil, groundwater, energy and space) and the contamination of other environments (directly through surface water and air emissions and indirectly through the production of waste)

The environmental merit perspective aims at quantifying the performances of candidate cleaning-up options along these evaluation criteria. This results into an environmental performances table, which is at the basis of the comparison of alternatives. Since these criteria largely represent independent concerns for the cleaning-up operations (cf. Drunen *et al.,* 1997), the approach through additive value functions can be applied to rank the alternatives in terms of environmental performances (Beinat, 1997). The assessment of value functions is rather simple in this case, since they emerge as linear functions. The reason is that the total environmental stocks behind each individual aspect are orders of magnitude larger than the amounts involved in each cleaning-up operation.

Table 2. The evaluation aspects for environmental merit. The "eq." label indicates that the impacts are a combination of quantity-quality factors.

Aspects	Units
Positive outcomes	
Improvement of soil quality	[m^3 eq]
Improvement of ground water quality	[m^3 eq]
Prevention of ground water pollution	[m^3 eq]
Negative outcomes	
Soil use	[m3]
Groundwater use	[m3]
Energy consumption	[J]
Air emissions	[ton]
Surface water emissions	[m^3 eq]
Waste produced	[m^3]
Space occupied	[m^2 . year]

Examples of value functions are given in Figure 2. The energy curve, for instance, associates to each energy consumption a value score between 0 and a negative value. The value of -1 is attached to a reference score selected for evaluation purposes which serves as an anchor point. If a remedial alternative does not consume fossil fuels, its normalised score will be 0. The higher the consumption, the more negative the normalised score.

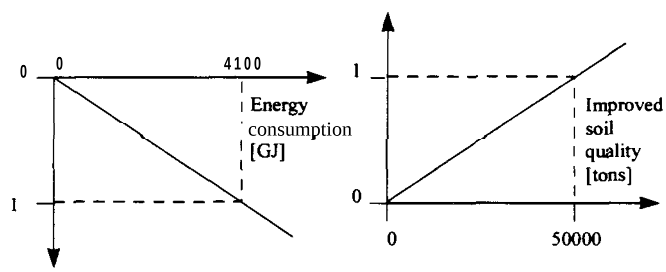

Figure 2: Example of value functions for energy consumption and improvement of soil quality.

The overall environmental quality of a remedial option is a weighted combination of the normalised scores. Intuitively, weights represent the relative importance of one attribute compared to another. The higher the weight attached to an aspect, the more the aspect drives the evaluation. Weights are assessed through interviews. Precise question answer protocols are used to ensure that the respondent provides weights which are a true representation of his/her decision strategy. It is very important to note that weights answer to the following question: “How much would you give up in a variable to achieve a given improvement on another?“. Therefore, weights are exchange rates between aspects. The interpretation of weight as a concept of importance or priority is not sufficient in this context. We do not ask people simply “which criteria is more important” but “how much do you want to trade-off between criteria”. This distinction is far beyond a pure academic consideration. It actually distinguishes between an intuitive estimate of importance (linked to general perceptions, feelings and attitudes of a person) and a precise statement of the decision strategy to be applied in practice (Keeney, 1992). There are several assessment strategies which can be followed for assessing the weights (see Beinat, 1997). The so-called swing technique is the most frequently applied and has been used within the present framework. Figure 4 shows a summary of the weights for 8 experts interviewed in this case. As it can be seen the differences between experts can be substantial.

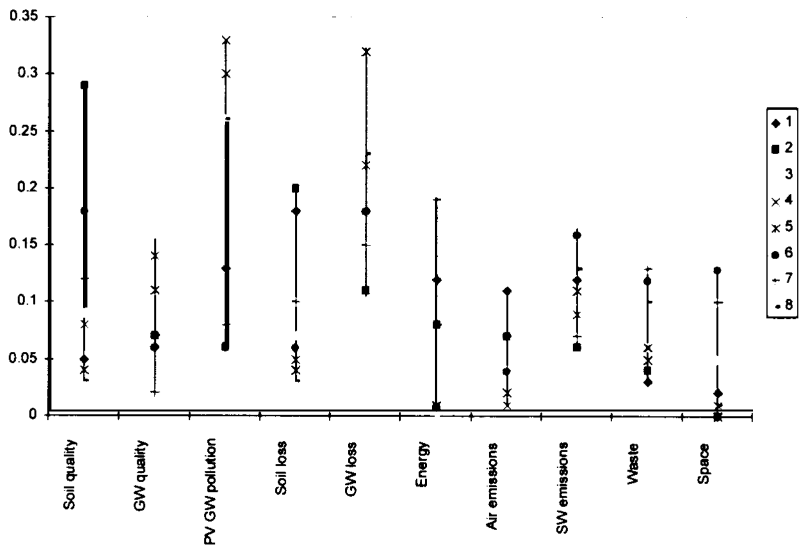

Figure 4. Weights for 8 interviews with soil and environmental experts.

The weighted sum of the normalised scores provides the indication of the overall performances, i.e. the environmental merit score. This can be used to rank the remedial options from the best to the worst in terms of the environmental merit perspective.

CHARACTERISTICS OF THE APPROACH

There are fundamental questions raised by this approach to environmental merit:

1. Does the current practice of soil remediation lead to a positive balance for the environment?
2. Who and how many experts should be interviewed?
3. Are the difference in opinion across experts significant for the evaluation.

To answer to the first question it is necessary to highlight a situation which can be seen as representative of the normal outcomes of soil remediation. Since it is extremely difficult to select an "average" cleaning-up situation due to the enormous differences between the size of the site, the type and concentrations of the compounds involved, in this paper a choice has been made to select the most frequent type of operation. In the Netherlands, this usually concerns a small-medium site (around 5000 m^3 of soil) with contaminants including mineral oil, chlorinated compounds and heavy metals. By collecting a large amount of information on sites of these characteristics and by "averaging out" the performances of current cleaning-up technologies, a reference environmental performance can be selected. This reference performance, which together with the status-quo has also been used for the weight assessment, can be rated with the environmental merit index. The results are shown in Figure 5. As it can be seen, all experts interviewed agree on the fact that the environmental performance of this reference situation is negative compared to the status quo, indicating a negative environmental balance. This is an important conclusion, since it points out rather clearly that the environmental effects of remediation should be carefully considered and that they cannot be assumed to be positive in all cases. However, it is also important to stress that a soil remediation is meant, above all, to provide risk reduction in the proximity of the contaminated site. Since all remedial operations do achieve this result, the total environmental balance of the operations has to account for the risk reduction and the environmental merit performances simultaneously. On the basis of the results shown in Figure 5, it can be speculated that either risk reduction has been considered as the only relevant evaluation criteria so far, or that negative environmental consequences are generally compensated for by sufficient risk reduction on the site.

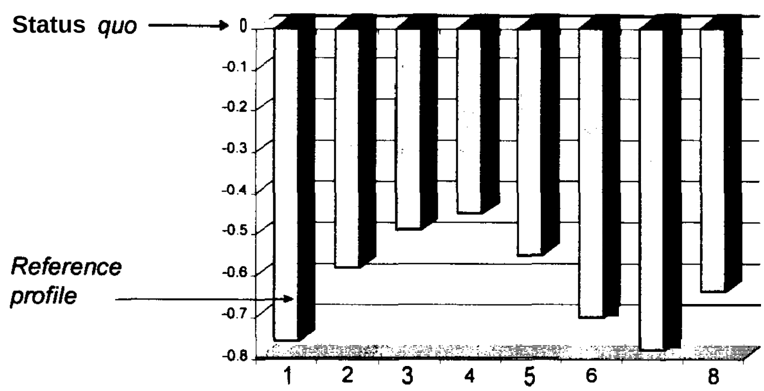

Figure 5. The environmental performance of a reference situation. Each bar corresponds to the environmental index of an expert.

The composition of the expert panel is also a critical issue. Weights should be assessed by those who have the power and role of evaluating the alternatives and fixing priorities for evaluation. Environmental performances regard non-local and public aspects. Thus, this power resides in some supra-local, public authority, for instance the national government or the provinces. In addition, weights can be different for different situations. In areas affected by groundwater scarcity, for example, the weights attached to groundwater effects are likely to be higher than in areas affected by soil quality problems. Consequently, it is necessary to test the variability of weights for different conditions. In the example shown in this paper, the weights are assessed by a panel of eight experts which have been interviewed separately. They include experts working for the provinces, city councils, the Ministry of Environment, but also for large companies. Each expert declared his/her reference situation for the assessment, thus setting a framework for the evaluation. Three main settings emerged in this case:

- the experts focusing on the soil issue, thus referring to an area where the availability and quality of soil was particularly important;
- the experts focusing on the groundwater issue, thus referring to an area where the availability and quality of groundwater was particularly important;
- the experts focusing on an urban environment, where the soi!, space and water quality are particularly important;

This is summarised in Table 2, which shows the affiliation and perspective of each of the experts interviewed. It is interesting to highlight that one of the experts (E,) did not complete the assessment. This expert was essentially concerned with the cost of the remedial alternatives, and disregarded environmental aspects. This made it impossible to proceed to an assessment of his priorities for environmental consequences, since they were totally irrelevant in his decision perspective.

Table 2: Experts, perspectives and affiliation.

	Public	Private
Soil	E_2	E_1- E_7- E_9
Groundwater	E_3- E_4- E_5	E_8
Urban	E_6	

Finally, it is important to highlight the effect of different weights on the ranking of alternatives. This is shown in Figure 6, which is the outcome of a real application case with four alternatives. The left hand side figure shows that different expert opinion leads to different estimated of the environmental balance of a remedial option (in this figure only six experts are shown). Thus, the cardinal value of the environmental index largely depends on the specific set of weights attached to the evaluation criteria. However, the overall indication of the group of experts is largely consistent with the average of expert indices shown in the lower part of the figure.

The ordinal content of the Environmental merit index is rather stable across experts. It can be easily seen from the right part of the figure that only few rank reversals occur between experts and that the overall position of the expert panel on the ranking of the alternatives is very strong and indicates a rather clear choice. This pattern of results has been obtained in almost all tests performed with the methodology.

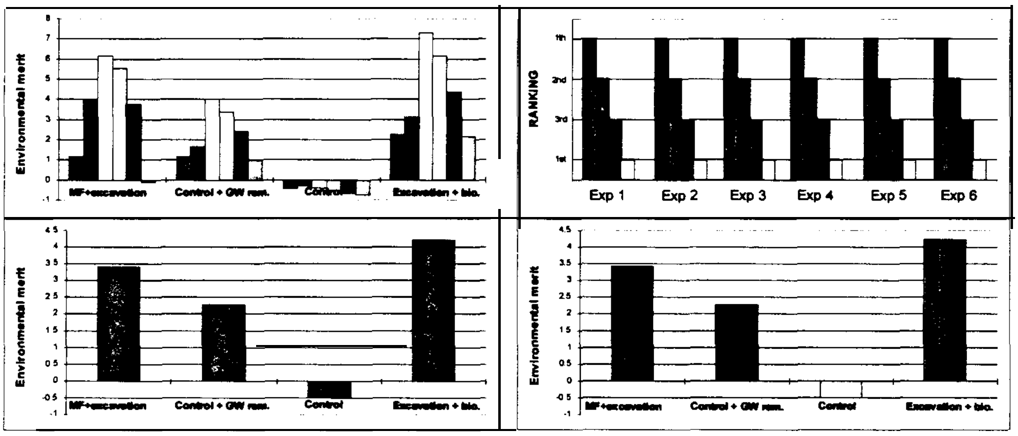

Figure 6. Application of the environmental index to a case study with 4 alternatives. The top diagram shows, for each alternatives, the value of the index for each expert. The bottom diagram shows the average value for each alternative.

CONCLUSIONS AND DISCUSSION

The analysis of the current practice of soil remediation highlights that a more comprehensive evaluation framework has to be considered in order to respond to the application needs. The REC framework presented in this paper shows how to combine risk reduction, environmental performance and costs of remedial actions systematically.

The use of an environmental merit index, as described in the paper, shows that the environmental balance of soil cleaning-up cannot be assumed to be positive in all cases. Instead, it should be considered as an objective of the cleaning up operations to be achieved by carefully designing remedial activities. This raises an important issue in decision making for soil remediation. The design of cleaning-up strategies is normally carried out independently of their evaluation. The set of candidate cleaning-up alternatives for a site is usually selected on the basis of the suitability of the technique for the type of soil and pollution involved. Each alternative is often a package of activities (like digging, removing, treating, etc.) which are performed simultaneously or with a precise timing and sequence. Once potentially suitable options are designed, they are evaluated and compared in order to choose the most effective and efficient one. By using a scheme like the environmental merit index in a reverse fashion, it is not only possible to evaluate existing strategies, but to support the design of innovative options which aim at achieving better environmental merit performances. This possibility, which is a future development still to be explored in its methodological and practical implications, has raised the largest interest amongst the end users which have so far applied the REC methodology. This approach would increase the effectiveness not only of the remedial operations, but also of the design of remedial actions.

In addition to these issues, it is worth recalling the estimates provided in Table 1. As mentioned earlier, it is of paramount importance to improve the monitoring and classification systems for polluted sites. Differences in the existing systems across Europe, and in the rest of the world, are incapable of providing a uniform and coherent picture of soil pollution. The implicit risk is that different approaches to the estimate of soil pollution may become a justification for different approaches to cleaning-up. This will make extremely difficult to state the degree to which soil pollution is addressed and the quality of its results. A substantial research effort is needed to improve the quality and use of soil quality and soil pollution indices which are widely accepted.

Acknowledgements

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